Class 11 Chemistry · Chapter 6: Equilibrium

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. 0.1 M aqueous solutions of HCl, NH_4Cl, NaCl and CH_3COONa at 298 K, in increasing order of pH, are [1]

(a) HCl < NH_4Cl < NaCl < CH_3COONa (b) NH_4Cl < HCl < NaCl < CH_3COONa

(c) HCl < NaCl < NH_4Cl < CH_3COONa (d) CH_3COONa < NaCl < NH_4Cl < HCl

Answer: (a) HCl is a strong acid (pH 1). NH_4^+ hydrolyses to give H^+, so NH_4Cl is mildly acidic. NaCl, from a strong acid and a strong base, is neutral (pH 7). Acetate hydrolyses to give OH^-, so CH_3COONa is basic.

2. With concentrations in mol L^{-1}, the unit of Kc for $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ is [1]

(a) mol L^{-1} (b) L mol^{-1}

(c) L^2 mol^{-2} (d) none; Kc has no unit

Answer: (c) $K_c = [NH_3]^2/[N_2][H_2]^3$, so its unit is $(mol\ L^{-1})^2/(mol\ L^{-1})^4 = (mol\ L^{-1})^{-2} = L^2\ mol^{-2}$.

3. For which equilibrium is Kp equal to Kc at every temperature? [1]

(a) $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ (b) $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$

(c) $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ (d) $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

Answer: (b) $K_p = K_c(RT)^{\Delta n}$, so Kp = Kc only when $\Delta n = 0$. For $N_2 + O_2 \rightleftharpoons 2NO$, $\Delta n = 2 - 2 = 0$; the others have $\Delta n = +1, -1$ and $+1$.

4. A sparingly soluble salt dissolves as $MX_2(s) \rightleftharpoons M^{2+}(aq) + 2X^-(aq)$. In its saturated solution at 298 K, $[X^-] = 2.0 \times 10^{-4}$ mol L^{-1}. The Ksp of MX_2 is [1]

(a) 4.0×10^{-12} (b) 3.2×10^{-11}

(c) 2.0×10^{-8} (d) 8.0×10^{-12}

Answer: (a) $[X^-] = 2S$, so $S = [M^{2+}] = 1.0 \times 10^{-4}$ mol L^{-1}. $K_{sp} = [M^{2+}][X^-]^2 = (1.0 \times 10^{-4})(2.0 \times 10^{-4})^2 = 4.0 \times 10^{-12}$. Taking $S = 2.0 \times 10^{-4}$ and using $4S^3$ gives 3.2×10^{-11}; forgetting the square gives 2.0×10^{-8}.

5. A cook at a hill station, where the atmospheric pressure is about 0.70 bar, heats water in an open pan. The water boils [1]

(a) at exactly 100 °C, as pure water always does (b) above 100 °C, because the air at the hill station is colder

(c) below 100 °C, because the pressure over it is less than 1.013 bar (d) only when its vapour pressure reaches 1.013 bar

Answer: (c) Water boils when its vapour pressure equals the pressure above it. The normal boiling point, 100 °C, is for 1.013 bar; at 0.70 bar the vapour pressure reaches the outside pressure at a lower temperature, so the boiling point falls with altitude.

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6. Kc for a reaction is measured twice at the same temperature, starting from different initial concentrations, and once more at a higher temperature. Which of the three values will differ, and why? [2]

The two values at the same temperature are equal, because Kc does not depend on the initial concentrations. The value at the higher temperature differs, because an equilibrium constant has one value for a given balanced equation at a given temperature and changes when the temperature changes.

- same temperature: equal, Kc independent of initial concentrations (1)
- higher temperature: different, Kc depends on temperature (1)

7. Explain why the pH of a dilute acetic acid solution rises when solid sodium acetate is dissolved in it. [2]

Sodium acetate ionises completely and supplies CH_3COO^-, an ion already present in $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$. By Le Chatelier's principle the equilibrium shifts towards undissociated acetic acid (the common ion effect), so $[H^+]$ decreases and the pH rises.

- acetate is a common ion; equilibrium shifts to the left (1)
- $[H^+]$ falls, so pH rises (1)

8. A student writes: "At chemical equilibrium the forward and reverse reactions stop." Correct the statement, and name one experiment from the chapter that shows the student is wrong. [2]

At equilibrium both reactions continue at equal rates, so there is no net change in composition; the equilibrium is dynamic. Evidence: when an H_2–N_2–NH_3 equilibrium mixture is mixed with a D_2–N_2–ND_3 mixture, NH_2D, NHD_2 and HD appear although the amount of ammonia is unchanged, so the reactions have not stopped (the radioactive sugar experiment is also accepted).

- reactions continue at equal rates; dynamic, not static (1)
- names the deuterium (or radioactive sugar) experiment and what it shows (1)

9. In the two-cylinder activity on dynamic equilibrium, coloured water is transferred from cylinder 1 to cylinder 2 with one glass tube and back with another. (a) Why do the levels in the two cylinders become constant? (b) What shows that the process is dynamic? (c) What happens if the two tubes have different diameters? [3]

(a) The levels become constant when, in each cycle, the volume carried from 1 to 2 equals the volume carried from 2 to 1: the two rates become equal. (b) Transfer continues after the levels are constant, just as forward and reverse reactions continue at equilibrium (level stands for concentration). (c) Equilibrium is still reached, but the two constant levels are different, since equal rates now need different levels.

- (a) equal transfer in both directions, i.e. equal rates (1)
- (b) transfer continues with no change in levels (1)
- (c) levels become constant but unequal (1)

10. In the Haber process, $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$; $\Delta H = -92.38$ kJ mol^{-1}. Explain why the plant (a) works at a high pressure of about 200 atm, (b) does not work at a low temperature although low temperature favours the yield, and (c) uses an iron catalyst. [3]

(a) Four moles of gas give two; by Le Chatelier's principle a higher pressure shifts the equilibrium towards NH_3, the side with fewer moles, raising the yield. (b) The reaction is exothermic, so K is larger at low temperature, but at low temperature the reaction is too slow to reach equilibrium in reasonable time; about 500 °C is a compromise between rate and yield. (c) Iron gives a satisfactory rate at a temperature where the equilibrium amount of NH_3 is still reasonably favourable; it does not change K or the equilibrium yield.

- (a) fewer moles of gas on the product side, so high pressure raises yield (1)
- (b) low temperature favours yield but rate is too slow; compromise temperature (1)
- (c) catalyst increases rate without changing equilibrium (1)

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11. A saturated solution of CaF_2 in pure water at 298 K is found to have $[Ca^{2+}] = 1.10 \times 10^{-3}$ mol L^{-1}. (a) Calculate Ksp of CaF_2. (b) Taking Ksp = 5.3×10^{-9}, what concentration of F^-, supplied by NaF, would lower the solubility of CaF_2 to 1.0×10^{-6} mol L^{-1}? (c) Explain the fall in solubility. ($1.10^3 = 1.331$; $\sqrt{53} = 7.28$) [3]

(a) $CaF_2(s) \rightleftharpoons Ca^{2+} + 2F^-$; in pure water $[F^-] = 2[Ca^{2+}] = 2.20 \times 10^{-3}$ mol L^{-1}, so Ksp = $[Ca^{2+}][F^-]^2 = 4S^3 = 4 \times 1.331 \times 10^{-9} = 5.32 \times 10^{-9} \approx 5.3 \times 10^{-9}$. (b) With $S = 1.0 \times 10^{-6}$, the F^- from CaF_2 is negligible, so Ksp = $S[F^-]^2$: $[F^-]^2 = 5.3 \times 10^{-9}/1.0 \times 10^{-6} = 5.3 \times 10^{-3}$, $[F^-] = 7.28 \times 10^{-2} \approx 0.073$ M. (c) F^- is a common ion; by Le Chatelier's principle the added F^- pushes $CaF_2(s) \rightleftharpoons Ca^{2+} + 2F^-$ to the left, so less salt dissolves before Qsp reaches Ksp.

- (a) $[F^-] = 2[Ca^{2+}]$; Ksp = $4S^3 = 5.3 \times 10^{-9}$ (1)
- (b) $[F^-] \approx 0.073$ M (1)
- (c) common ion shifts the equilibrium towards the solid (1)

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